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Black Hawk Helicopter Vibration Analysis Due to Main Rotor Damage, Directional Constituents of the Resultant Vibrations

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Black Hawk Helicopter Vibration Analysis Due to Main Rotor Damage, Directional Constituents of the Resultant Vibrations

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Abstract

Black Hawk helicopter cockpit vibrations due to main rotor damage are presented based upon an analysis and computer code originally developed in-house in the Air Systems Branch (ASB) of the U.S. Army Research Laboratory (ARL). Ballistic damage is simulated by removing various amounts of the outer radius of one blade of the rotor set of four blades. This simulated blade damage causes the rotor to be unbalanced allowing undesirable vibrations to be transmitted into the fixed-system airframe. This work considers the longitudinal, lateral, and vertical cockpit amplitude and phase components of the vibrations that make up the total vector vibrations that a cockpit occupant would feel. If the vibrations are severe enough, they could lead to attrition of the aircraft. This vibration data can be used in conjunction with historical human-vibration-tolerance data for later work toward determining a pilot's capability to function in the helicopter cockpit vibration environment.

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1. Introduction

A helicopter-vibration computer code (RTVIB20) was developed by the author [1] to analyze vibrations transmitted into the fixed system by a variety of main rotor-blade damages. In this present study, this code is used to investigate Black Hawk helicopter cockpit vibrations due to the removal of outer sections of one blade of the rotor set of four blades. Such a condition may be the result of ballistic damages. The cockpit vibrations are examined in resultant form for each harmonic from 1/Rev (revolution) to 5/Rev and then in directional constituent cosine and sine form. The harmonic component of the vibrations (fixed system) can originate from harmonics in the rotating blade system that are either of the same harmonic number as transmitted to the fixed system or a rotating harmonic shifted 1/Rev above or below the center frequency.

When the set of rotor blades is undamaged, the blades are called "matched" and cause an effect known as "filtering" to occur. Filtering blocks certain frequencies from being transmitted from the blades into the fuselage (fixed system). Only blade frequencies that are integer multiples of the number of blades can be transmitted from the rotor blades to the fuselage. For instance, for the Black Hawk helicopter with four blades comprising the main rotor, only 4/Rev, 8/Rev, 12/Rev, etc., vibrations can be transmitted.

However, if one or more blades are damaged thus making them have different physical properties from the others, all frequencies are transmitted into the fixed system that allows these unwanted frequencies to produce detrimental cockpit vibrations. These can cause structural fatigue and pilot-physiological debilitating effects. As an adjunct, historical human tolerance to vibration data can be integrated with the vibration data in this report to predict the effect on a pilot and his ability to continue to operate the aircraft.

The RTVIB20 code is documented in U.S. Army Research Laboratory (ARL) report TR-75 [1] and requires a GWBASIC compiler to execute. Later in 1996, RTVIB20 was updated to accommodate a helicopter tied to the ground with springs and dampers and named RTVIB21. Such a condition is applicable to helicopter ballistic vulnerability testing.

For this study, the RTVIB20 computer code was run for a Black Hawk helicopter simulation at 258-rpm main rotor speed, 16,260-lb gross weight, 160-kn forward speed, at a 4,000-ft pressure altitude, on a 95 °F day.

2. Presentation of Fixed-System Vibration Data

First, the resultant vibrations are shown in Figure 1 as G's (gravitational pull) vs. percent of the removal of the outer blade section.

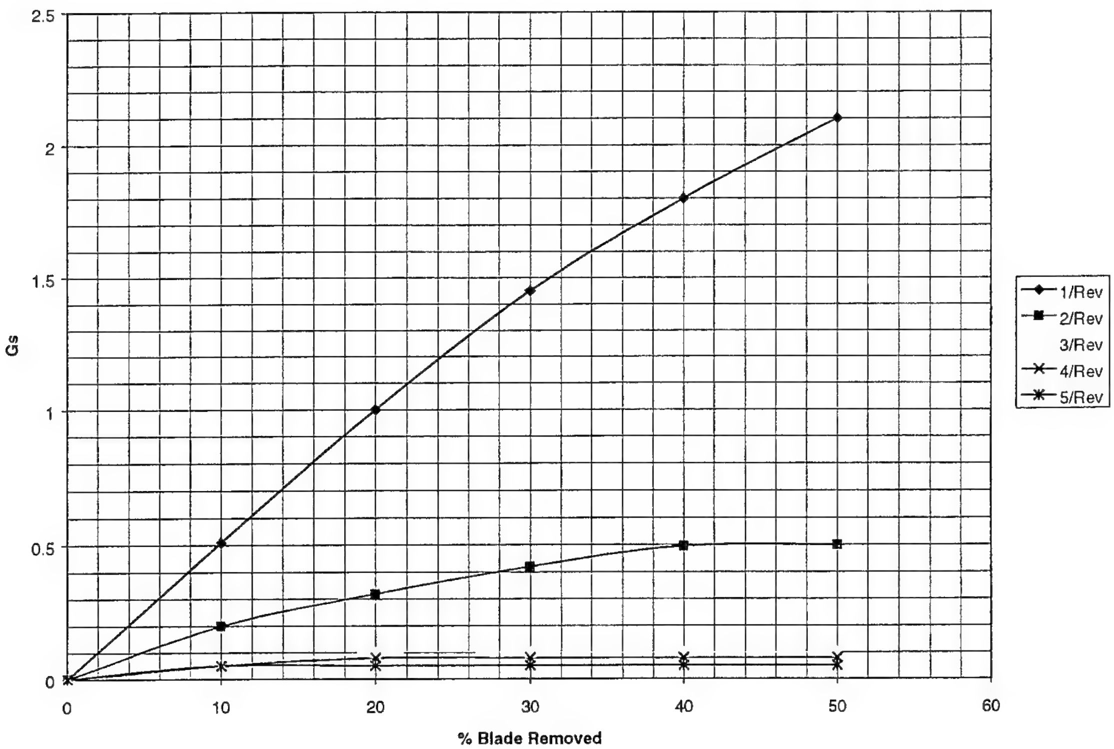

Figure 1. Cockpit resultant vibrations G's vs. percent of blade removed.

There is a predominate 1/Rev frequency getting through to the cockpit that ordinarily would be filtered out for undamaged blades of the set of four, and there is also a significant 2/Rev. The higher frequencies have low amplitudes, and it should be noted that the 4/Rev would be the only frequency transmitted if no damage were present.

Next, the individual harmonics are viewed one at a time, and the directional cosine and sine components are distinguished. In Figure 2, the legend is defined as follows:

- LNC = Longitudinal Cosine Vibration
- LNS = Longitudinal Sine Vibration
- LTC = Lateral Cosine Vibration
- LTS = Lateral Sine Vibration
- VTC = Vertical Cosine Vibration
- VTS = Vertical Sine Vibration

From Figure 1, it was found that the 1/Rev is the biggest resultant vibration, and the makeup in Figure 2 shows that the vertical cosine component is the biggest constituent followed by the lateral sine. The longitudinal cosine and vertical sine follow next in absolute amplitude. In a normal undamaged rotor, none of these 1/Rev vibrations would occur for a 4-bladed rotor.

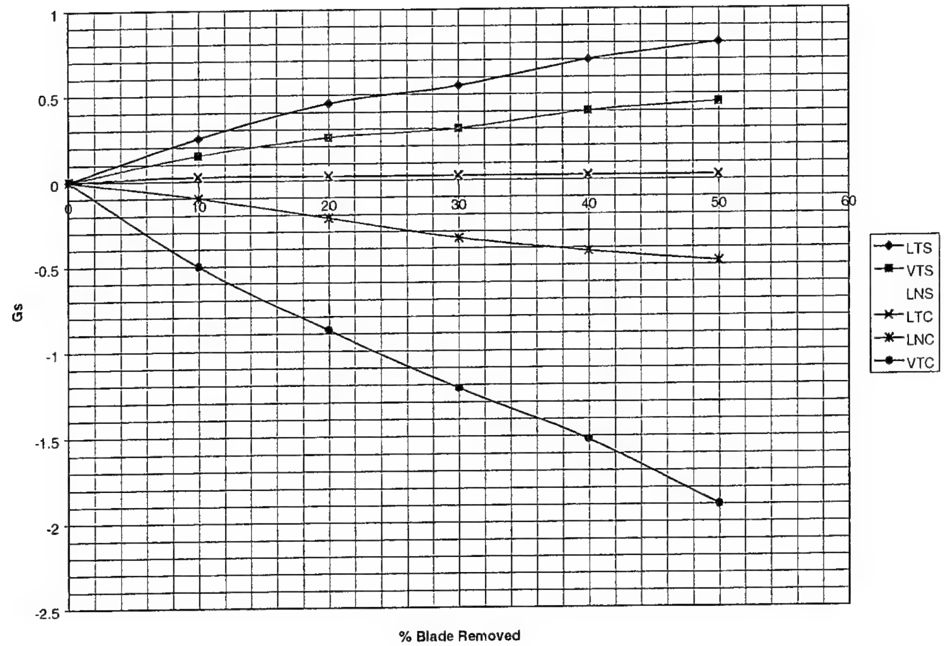

Figure 2. 1/Rev cockpit constituent vibrations G's vs. percent of blade removed.

Next in order are the 2/Rev vibrations illustrated in Figure 3. In a normal undamaged rotor, none of these 2/Rev vibrations would occur for a 4-bladed rotor.

Next are the 3/Rev vibrations illustrated in Figure 4. In a normal undamaged rotor, none of these 3/Rev vibrations would occur for a 4-bladed rotor.

The 4/Rev vibrations are illustrated in Figure 5. Notice that the vibrations for the undamaged blade (at 0% blade removed) are not zero. This is significant and points to the fact that 4/Rev is an integer number of the blades in the rotor and is not filtered out; it is an inherent vibration that always exists. Also notice that the amplitudes of these inherent vibrations are relatively low compared to the 1/Rev that exists when a blade is damaged. These are inherent 4/Rev vibrations that are always present in the cockpit for a 4-bladed rotor.

Finally, the 5/Rev vibrations are illustrated in Figure 6. The amplitudes are very small, which is as expected for the higher frequencies. Therefore, there is no need to continue to list the higher frequencies. None of these vibrations would occur for an undamaged 4-bladed rotor.

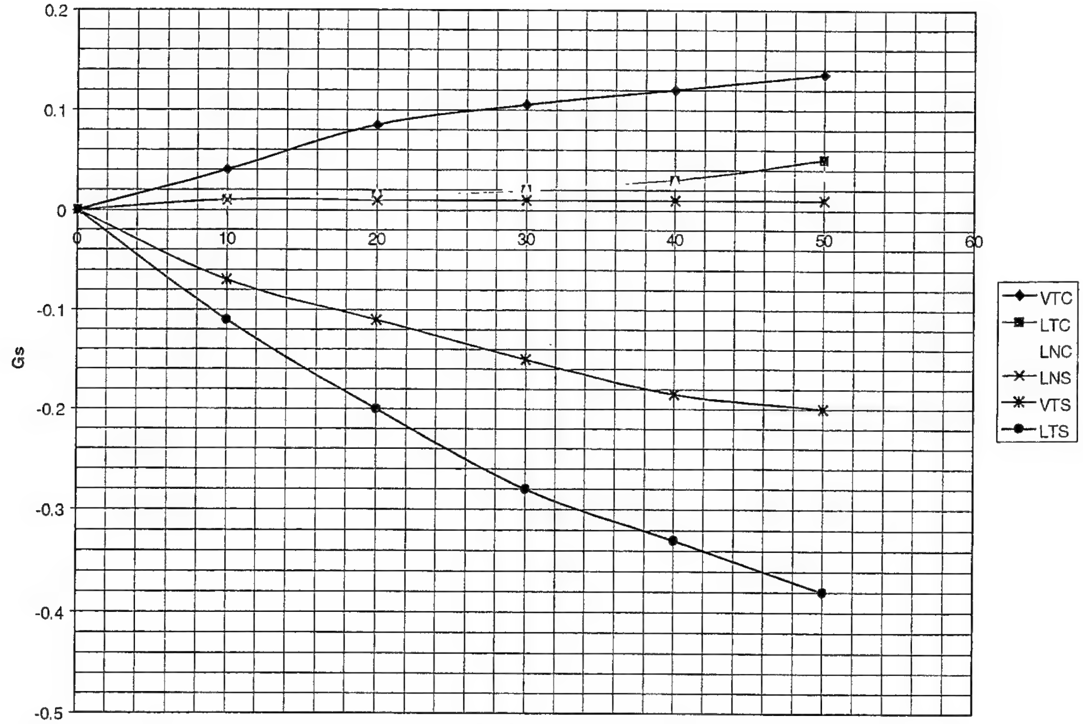

Figure 3. 2/Rev cockpit constituent vibrations G's vs. percent of blade removed.

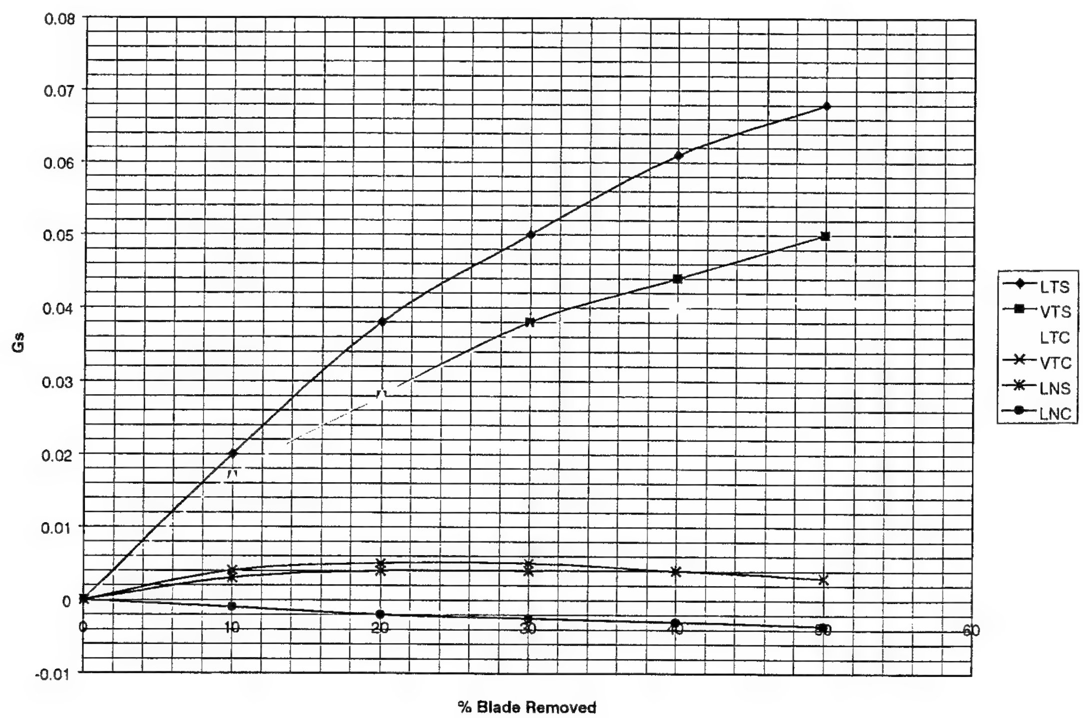

Figure 4. 3/Rev cockpit constituent vibrations G's vs. percent of blade removed.

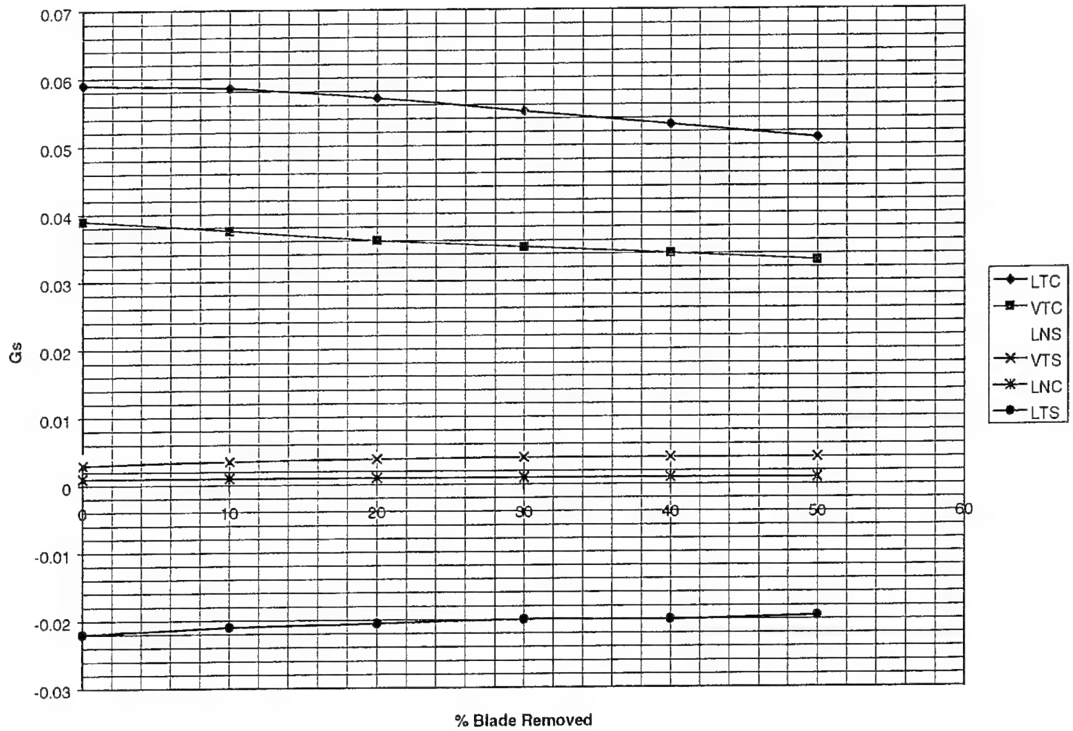

Figure 5. 4/Rev cockpit constituent vibrations G's vs. percent of blade removed.

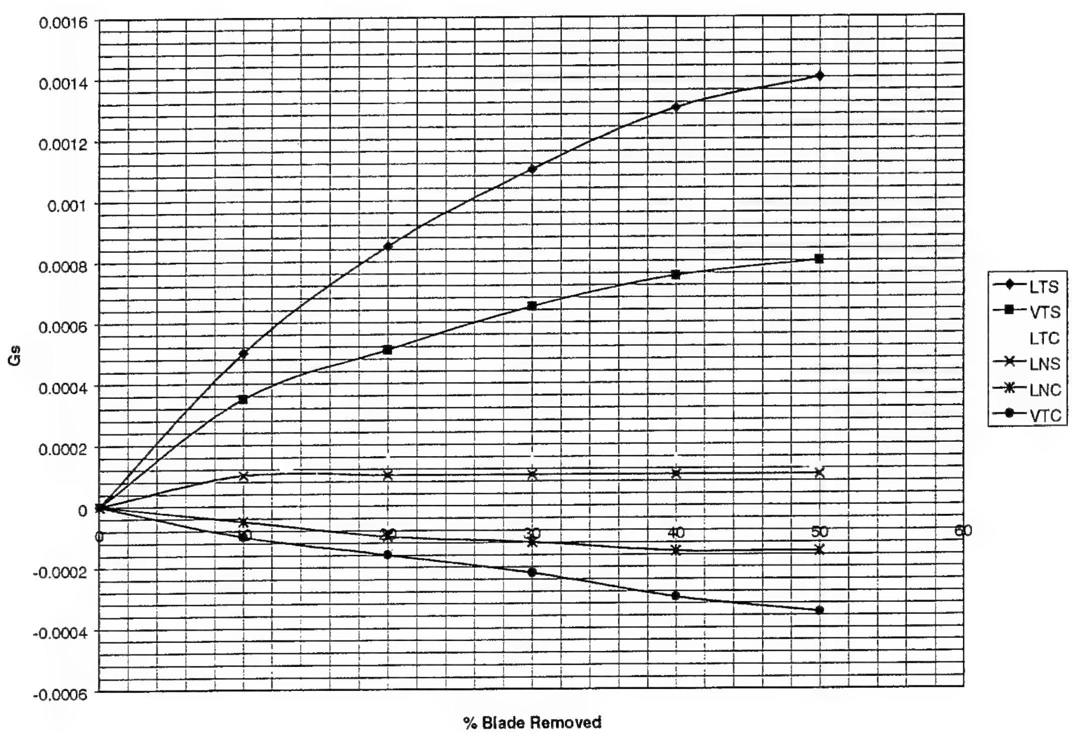

Figure 6. 5/Rev cockpit constituent vibrations G's vs. percent of blade removed.

3. Ranking of the Constituent Vibrations

In order to make sense of the data, ranking is needed for the constituent vibrations to determine which are the dominant vibration directions for each harmonic. Table 1 ranks the data with 6 representing the largest amplitude and 1 representing the smallest amplitude for each harmonic.

Table 1. Directional vibration constituents.

Weighted Numbers →	6	5	4	3	2	1
1/Rev	VTC	LTS	LNC	VTS	LNS	LTC
2/Rev	LTS	VTS	VTC	LTC	LNC	LNS
3/Rev	LTS	VTS	LTC	LNC	VTC	LNS
4/Rev	LTC	VTC	LTS	VTS	LNS	LNC
5/Rev	LTS	VTS	VTC	LNC	LTC	LNS

To get an idea which direction occurs most frequently among all the contributors from Table 1, a cumulative number can be determined by adding the weighted numbers for each direction. This number is calculated and shown in Table 2.

Table 2. Cumulative directional vibration constituents.

Direction	Cumulative Weight
LTS	27
VTS	21
VTC	21
LTC	16
LNC	13
LNS	7

From Tables 1 and 2, it can be seen that the lateral and vertical vibrations are dominant, but the longitudinal vibrations are relatively unimportant.

4. Discussion and Results

From Figure 1, it is seen that the dominant cockpit vibration comes from 1/Rev, which is the frequency of the main rotor (1 × 258 rpm) followed by the 2/Rev (2 × 258 rpm) in amplitude. As the frequency increases, the amplitude of vibration decreases as would be expected except if there is no resonance in the system. A separate study would be needed to determine how these vibrations might fatigue the structure of the aircraft or affect a pilot's ability to fly the aircraft.

As the damage of one blade of the rotor set increases by increasingly more of the outer blade being removed, the vibrations get worse as would be expected. All of the vibrations except the 4/Rev go through the origin of the charts because, in the undamaged state, the frequencies are filtered out and are not transmitted to the fuselage. This is the natural state of the helicopter. The only natural inherent vibration of an undamaged helicopter are the 4/Revs.

Figure 1 shows the cockpit vibration to be above 2 G's for the high-speed condition with half of one blade's outer portion lost. Further performance analysis would be needed to determine the helicopter's residual capability to survive or the pilot's capability to perform. Helicopter first principles can be found in works by Chopra [2], McCormick [3], and Saunders [4].

5. Conclusions

This analysis demonstrates an analytical capability to predict helicopter fixed-system vibrations to be used in the survivability estimation of rotary wing aircraft. It uses first principles of physics to develop a viable analysis and computer code and can be used in conjunction with structural analysis and human-vibration tolerance data to determine the performance state of a helicopter after suffering main rotor damage.

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